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by L. A. Imig

Langley Research Center

Langley Station, Hampton, Va.

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

The effect of high initial tensile or compressive loads and exposures up to 30 days at 300° and 550° F (422° and 561° K) on the room-temperature fatigue life of notched Ti-8Al-1Mo-1V titanium-alloy sheet was investigated. A high initial tensile load caused an increase in fatigue life and a high initial compressive load caused a decrease. Calculations showed that the tensile load caused compressive residual stress (which increased fatigue life) and that the compressive load caused tensile residual stress (which decreased fatigue life). Short duration exposure to elevated temperature caused a decrease in fatigue life. Longer exposures did not cause further reductions in fatigue life.

INTRODUCTION

The flight loadings encountered by an airplane may cause residual stresses in the airplane skin at points of stress concentration. It is generally accepted (refs. 1 to 6) that compressive residual stress in such areas provides a beneficial effect on fatigue life. Some of the investigations indicated that compressive residual stress provided an increase in fatigue life for prototype structures. (See refs. 1 to 3.) Others showed similar results for the effects of compressive residual stress on fatigue life for simple specimens (refs. 4 to 6). These previous investigations were conducted at laboratory ambient temperature.

However, projected airplanes to be flown at speeds in the Mach 2 to Mach 3 range will experience moderately elevated temperatures on large areas of the skin. Therefore,

*The information presented herein includes information from a thesis entitled "The Effect of Moderately Elevated Temperature on the Fatigue Lives of Notched ($K_T = 4$) Specimens Which Contain Residual Stress" offered in partial fulfillment of the requirements for the degree of Master of Science in Engineering Mechanics, Virginia Polytechnic Institute, Blacksburg, Virginia, April 1966.

it is of interest to anticipate the possibility of detrimental effects of the temperature on residual stress and on the fatigue life of the airplane.

The current project was initiated to obtain information about the effect of moderately elevated temperature on the room-temperature fatigue life of specimens containing residual stress. Notched specimens, having a theoretical elastic stress-concentration factor of 4 and made of duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet, were used. The investigation consisted of (1) determining changes in fatigue life due to application of the initial loads and (2) determining the effect of elevated temperature exposure on fatigue life of specimens similarly loaded initially. Exposures were at 300° and 550° F (422° and 561° K) and ranged up to 30 days.

The units used for the physical quantities defined in the tables and figures are given in both the U.S. Customary Units and in the International System of Units (SI). Factors relating the two systems (ref. 7) are given in appendix A. Throughout the paper, U.S. Customary Units will be followed parenthetically by SI Units.

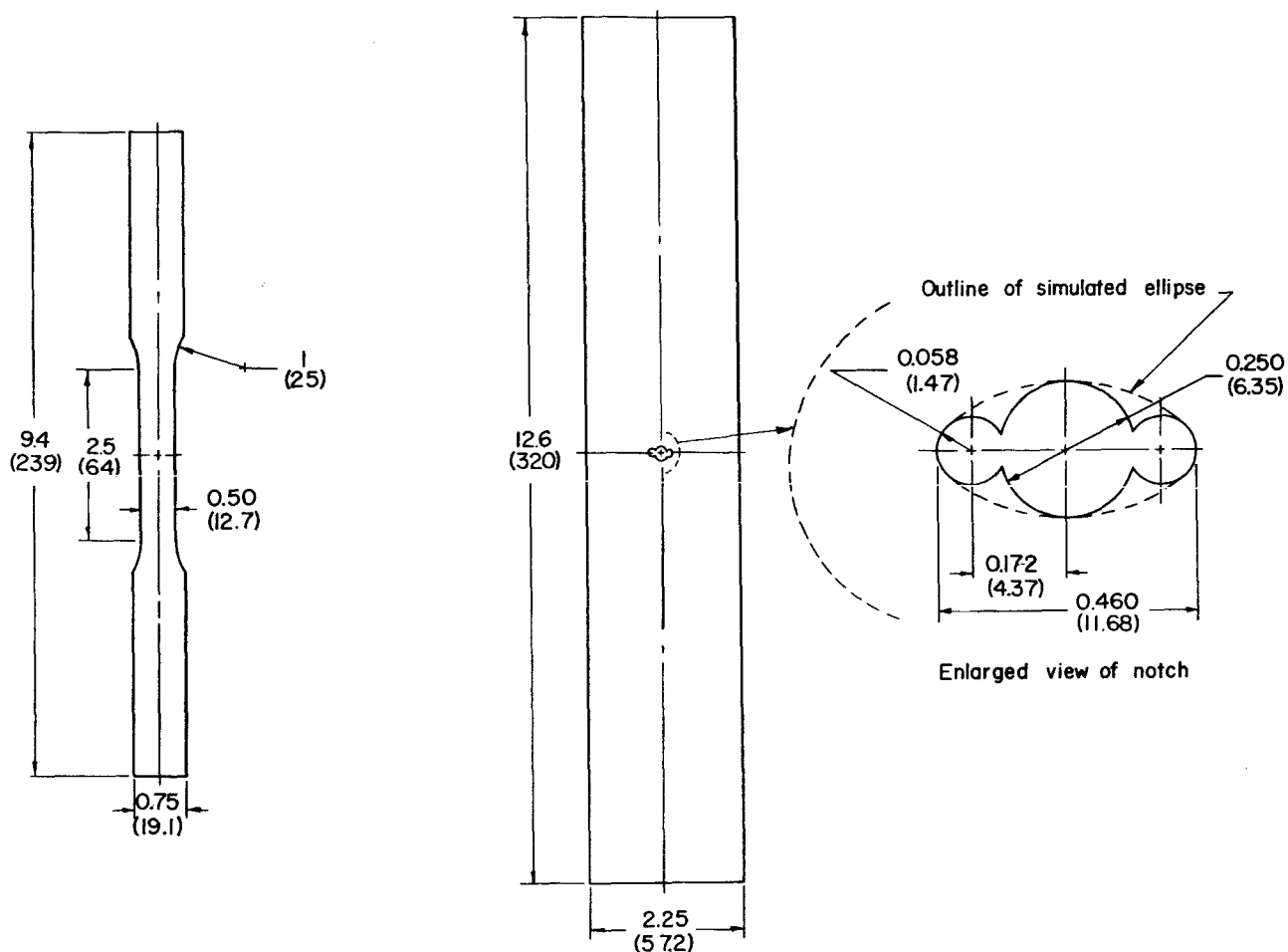
MATERIAL AND SPECIMENS

Material

The material used in this investigation was 0.050-inch-thick (1.27-mm) Ti-8Al-1Mo-1V titanium-alloy sheet in the duplex-annealed condition. The duplex-annealing procedure consisted of heating to 1450° F (1061° K) for 8 hours, furnace cooling, heating to 1450° F (1061° K) for 15 minutes, and air cooling. Table I lists the longitudinal tensile properties and the chemical composition of the material.

Specimens

The configurations of test specimens are given in figure 1. The longitudinal axis of all specimens was parallel to the rolling direction of the sheet. The surfaces of the specimens were left as rolled. Figure 1(a) shows the tensile specimen and figure 1(b) shows the fatigue specimen. The notch has a theoretical elastic stress-concentration factor of 4 (that is, $K_T = 4$). The notch configuration simulates an ellipse as shown in the figure. The dimensions of the ellipse were determined by the procedure developed by McEvily, Illg, and Hardrath (ref. 8). The radius at each end of the notch was made by successively increasing the drill size by increments of 0.003 inch (0.076 mm) beginning with an 0.110-inch (2.79-mm) drill. The small burrs produced by the drilling operation were removed by holding the specimen lightly against a rotating rod composed of rubber impregnated with an abrasive. The deburring operation resulted in a slight bevel around the circumference of the ends of the notch.



(a) Tensile specimen.

(b) Fatigue specimen.

Figure 1.- Tensile and fatigue specimen configurations. Dimensions are in inches with millimeter equivalents in parentheses.

TESTING EQUIPMENT AND EXPERIMENTAL PROCEDURE

Tensile Tests

Tensile tests were conducted in a universal testing machine with a 120-kip (530-kN) capacity. Stress-strain curves were obtained autographically by means of an x-y recorder. The electronic signal from a load cell in series with the specimen actuated the recorder drive for the stress axis. The strain axis was actuated by the output of an extensometer which incorporated a linear variable differential transformer. The extensometer was attached to the specimen in the reduced section and had a gage length of 1 inch (25.4 mm). The elongation in 2 inches (50.8 mm) was determined by measuring the distance, after fracture, between grid lines placed on each specimen prior to the test.

Fatigue Tests

Axial-load fatigue tests were conducted in a hydraulically actuated testing machine in which the loading was controlled through a closed-loop servosystem similar to that described in reference 9. A schematic diagram of the machine is shown in figure 2 and a photograph of the machine and electronic controls is presented as figure 3. An important feature of this equipment is that load amplitudes can be preset to allow accurate loading of specimens from the first cycle of the test. Load amplitudes are adjustable by means of the electronic signal from three variable resistors. Loading accuracy was verified during tests when a null indication was achieved on an oscilloscope in the readout balance system. The null was obtained when the difference between signals from the weighbar and a calibrated variable resistor in the readout system was zero. The accuracy of loading was estimated to be within ± 15 pounds (± 66 N) or ± 0.15 percent of capacity. For the present tests, a 10-kip (44-kN) capacity weighbar was used and the operating frequency was approximately 15 cycles per second.

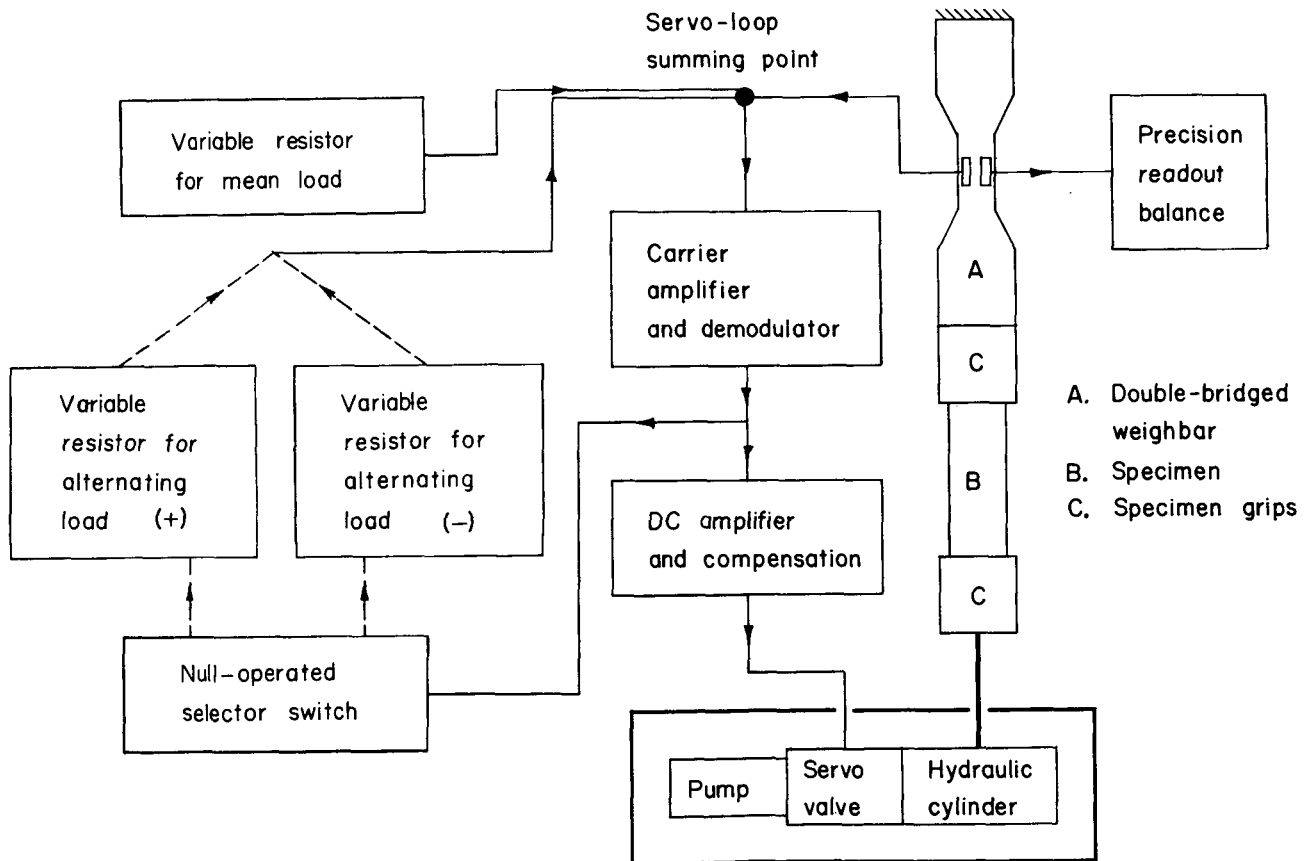
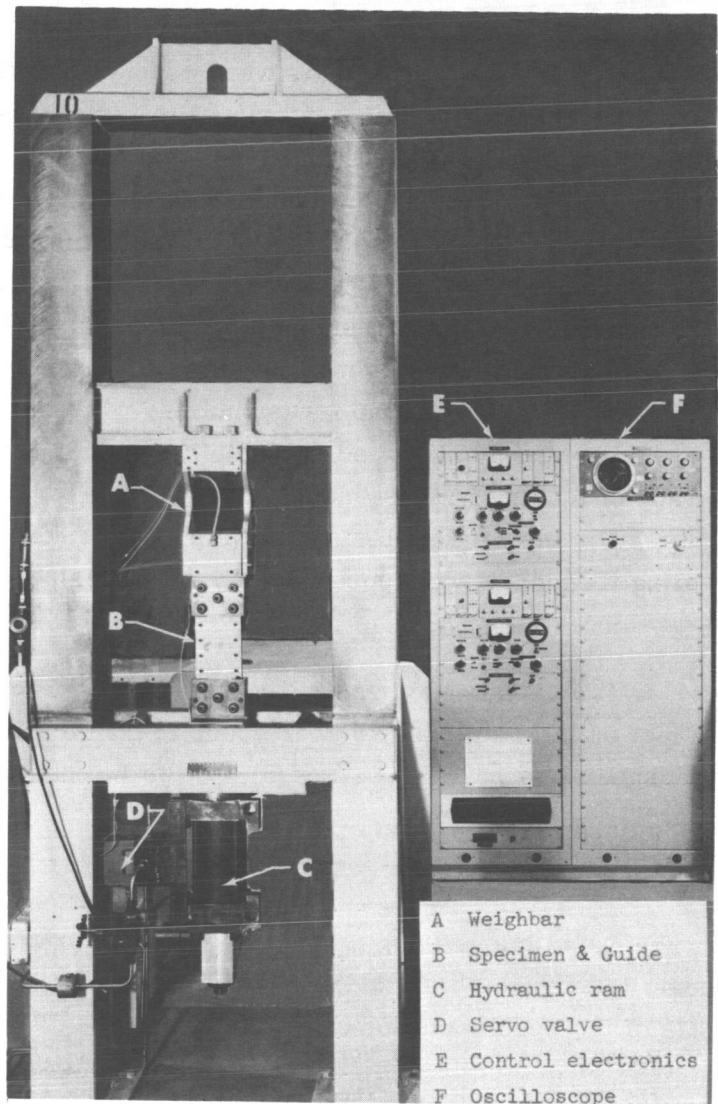


Figure 2.- Schematic diagram of hydraulically actuated closed-loop servo-controlled fatigue-testing machine.

The fatigue tests were conducted at a constant-amplitude stress range of 0 to 50 ksi (0 to 345 MN/m²) on the net section and loading was applied axially. Generally, five specimens were tested for each condition. The initial high tensile or compressive loads required to induce local residual stresses in the specimens were also applied in the fatigue machine. Guide plates were utilized on all specimens during compression loading in order to prevent specimen buckling. As the greatest effect of the initial loads on fatigue life was caused by high tensile loads, only the two highest tensile loads, 80 and 100 ksi (552 and 690 MN/m²) were used to determine elevated-temperature effects.

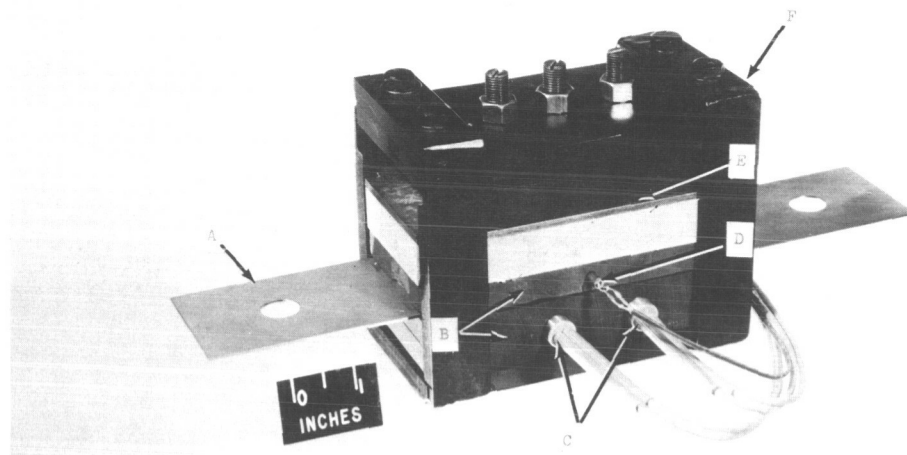
Specimens which had been initially loaded in tension were exposed up to 30 days at 70°, 300°, and 550° F (294°, 422°, and 561° K). The elevated temperatures are representative of the average structural temperatures anticipated during flight at Mach 2.2 and Mach 3, respectively.

Specimens exposed for less than 20 hours were placed in a preheated apparatus of the type shown in figure 4 in which heating is accomplished by specimen contact with the carbon slabs. Specimens exposed for 20 hours or more were heated in an oven. A fan circulated the air inside the oven to provide a uniform temperature distribution. In either case, the desired temperature was maintained within $\pm 10^\circ$ F (5.5° K). After the desired exposure, specimens were reinstalled in the testing machine for the fatigue test.



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Figure 3.- Photograph of hydraulically actuated closed-loop servo-controlled fatigue-testing machine and control console.



- A Specimen
- B Carbon slabs
- C Resistance heating elements
- D Thermocouple temperature sensor
- E Pressure plate for use when furnace acts as guide plate
- F Supporting frame

Figure 4.- Apparatus used for short duration specimen heating.

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To evaluate the possibility that elevated temperature alone might have a detrimental effect on the material, another group of specimens was exposed to 550° F (561° K) for 30 days without having been subjected to initial loading.

RESULTS AND DISCUSSION

Data obtained during the investigation are tabulated in tables II, III, and IV and are shown in figures 5, 6, and 7. The symbols in the figures give the geometric mean fatigue life of the specimens for each test condition. The scatterband, indicated by the tick marks, indicates the maximum and minimum fatigue life for that test condition. Fatigue life data from specimens which did not fail within 10^6 cycles were not included in the computation of geometric mean life.

Effect of Initial Tensile and Compressive Loads

The data shown in figure 5 were obtained by loading the specimens in tension or compression and subsequently testing them to failure in fatigue. The point plotted at zero stress gives the reference fatigue life. Fatigue lives much longer than the reference life were obtained from specimens which had experienced a large initial tensile load. The fatigue lives of specimens which had experienced an initial compressive load tended to be shorter than the reference life. (See table II.)

A qualitative consideration of the residual stress at the notch due to application of the conditioning load provides a basis for explaining the results shown in figure 5 as

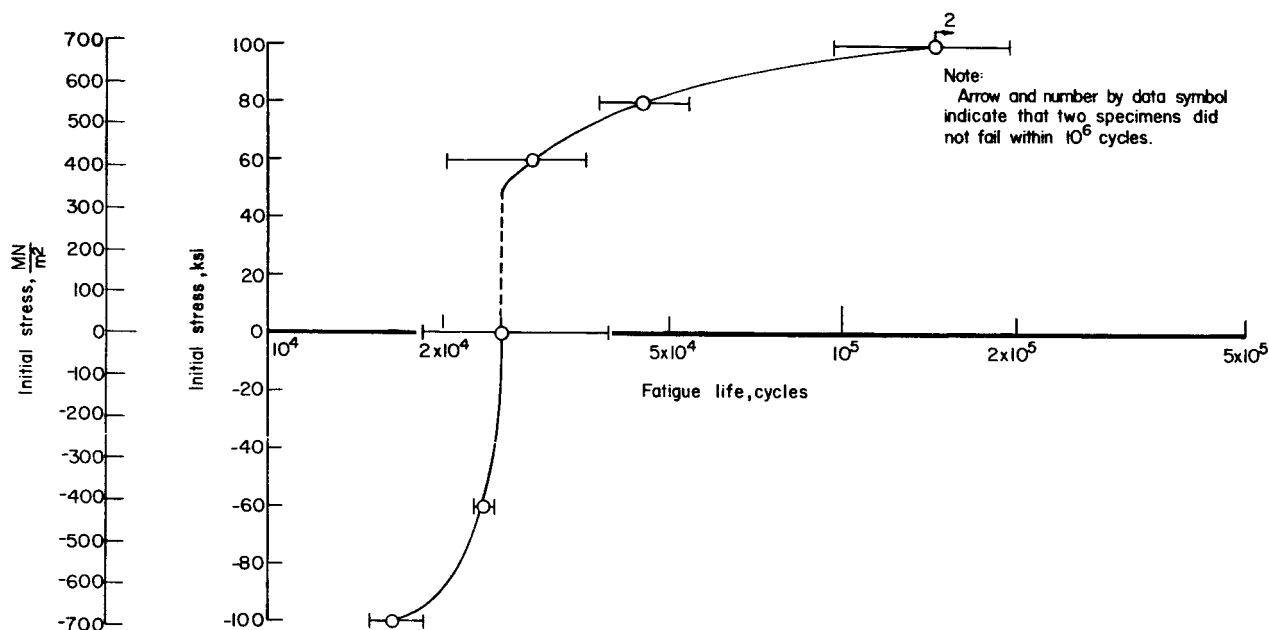


Figure 5.- The effect of an initial tensile or compressive load on the fatigue life of notched ($K_t = 4$) specimens of duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet. Cyclic stress range: 0 to 50 ksi (0 to 345 MN/m²).

follows: A tensile load which is large enough to cause yielding at the notch will produce a local compressive residual stress at the notch when the load is removed. (See ref. 10.) Subsequent application of a tensile load to the specimen containing the compressive residual stress would cause a lower local tensile stress than it would in an initially stress-free specimen. The reduced local stress is generally acknowledged as being responsible for the longer fatigue lives experienced by specimens initially loaded in tension. Figure 5 demonstrates that an increase in life by a factor of 10 was achieved for specimens conditioned at 100 ksi (690 MN/m²). By similar reasoning, initial compressive loads cause tensile residual stresses which result in a higher local stress than in initially stress-free specimens. As shown by figure 5, fatigue lives were reduced by compressive loading although the decrease is smaller than the increase due to tensile loading.

Effect of Elevated-Temperature Exposure

The data obtained from tests of specimens exposed to elevated temperature after tensile loading at 100 ksi (690 MN/m²) are presented in figure 6 and in table III. The reference fatigue life (lower point) and the life after application of a 100-ksi (690-MN/m²) stress (high point), corresponding to zero exposure time, are plotted at the left in

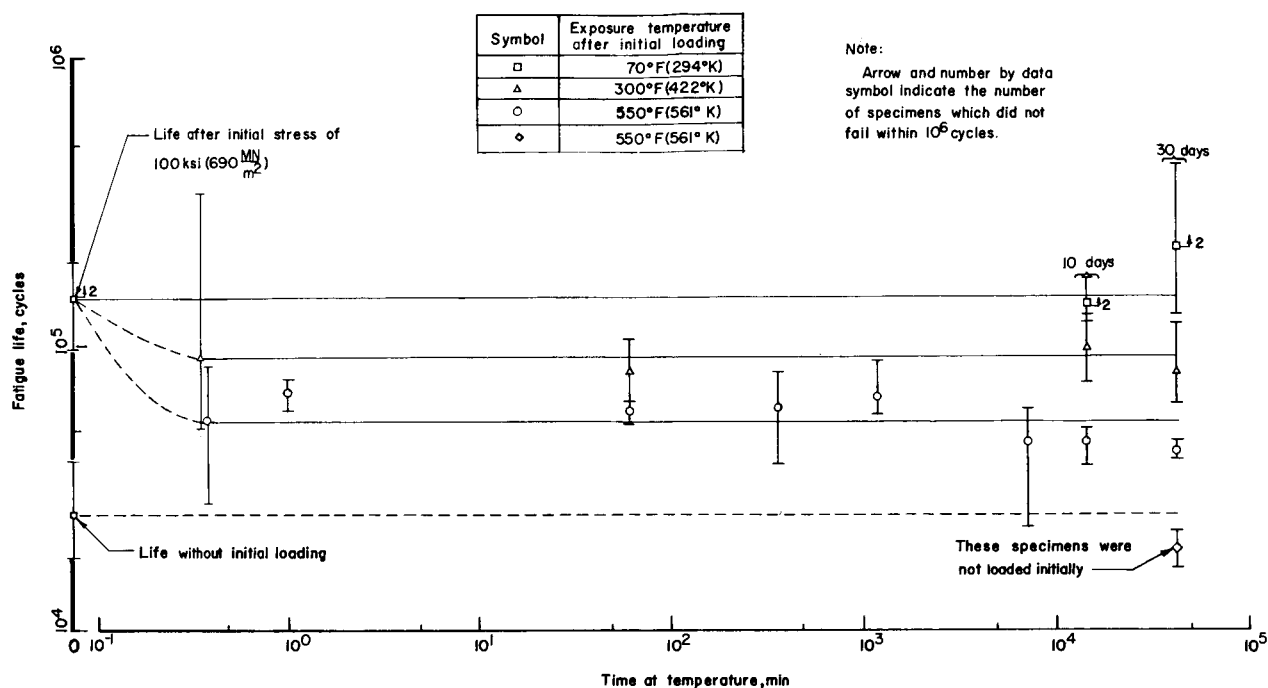


Figure 6.- The effect of exposure to elevated temperature on the room-temperature fatigue life of notched ($K_T = 4$) specimens of duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet loaded at 100 ksi (690 MN/m²). Cyclic stress range: 0 to 50 ksi (0 to 345 MN/m²).

figure 6. The three curves in the figures are identified by symbols according to the exposure temperature.

The scatterbands for fatigue lives after 10 days and 30 days of exposure at 70° F (294° K) were approximately the same as that noted for specimens tested without exposure. (See fig. 6.) The fatigue lives dropped sharply, however, after only 20 seconds of exposure at 550° F (561° K). The lives obtained after exposures up to 30 days were approximately the same as for a 20-second exposure. The effect of temperature on fatigue life was not as pronounced for exposure at 300° F (422° K) as for exposure at 550° F (561° K) although the data show similar behavior. In neither case did the fatigue life diminish to the life before tensile loading. The heating apparatus used for the short exposures required 20 seconds to reach the control temperature. Therefore, the data in figure 6 for an exposure of 20 seconds were obtained from specimens which had just reached the desired temperature at the time they were removed from the heating apparatus.

If residual compressive stresses are accepted as causing the beneficial effects on fatigue life discussed previously, the short exposure at elevated temperatures must have reduced the residual stresses substantially in order to cause such a significant change in fatigue life. Other tests (ref. 11) have shown that the tensile yield strength of the duplex-annealed Ti-8Al-1Mo-1V titanium alloy is 94 ksi (650 MN/m²) at 550° F (561° K)

compared with 134 ksi (925 MN/m²) at room temperature. Thus, residual stresses which are greater than the elevated-temperature compressive yield stress and which are stable at room temperature would relax very quickly to approximately the elevated-temperature yield stress when the material is heated to 550° F (561° K).

The fatigue life data for specimens which were exposed to 550° F (561° K) for 30 days without having been loaded initially are shown at the right of figure 6 and are given in table III. The reduction in life observed for these specimens is probably not significant because the data fall within the scatterband of lives for the reference condition.

The effect of the elevated temperature exposure on the fatigue lives of specimens loaded at 80 ksi (552 MN/m²) is shown in table IV and figure 7. Exposure at 70° F

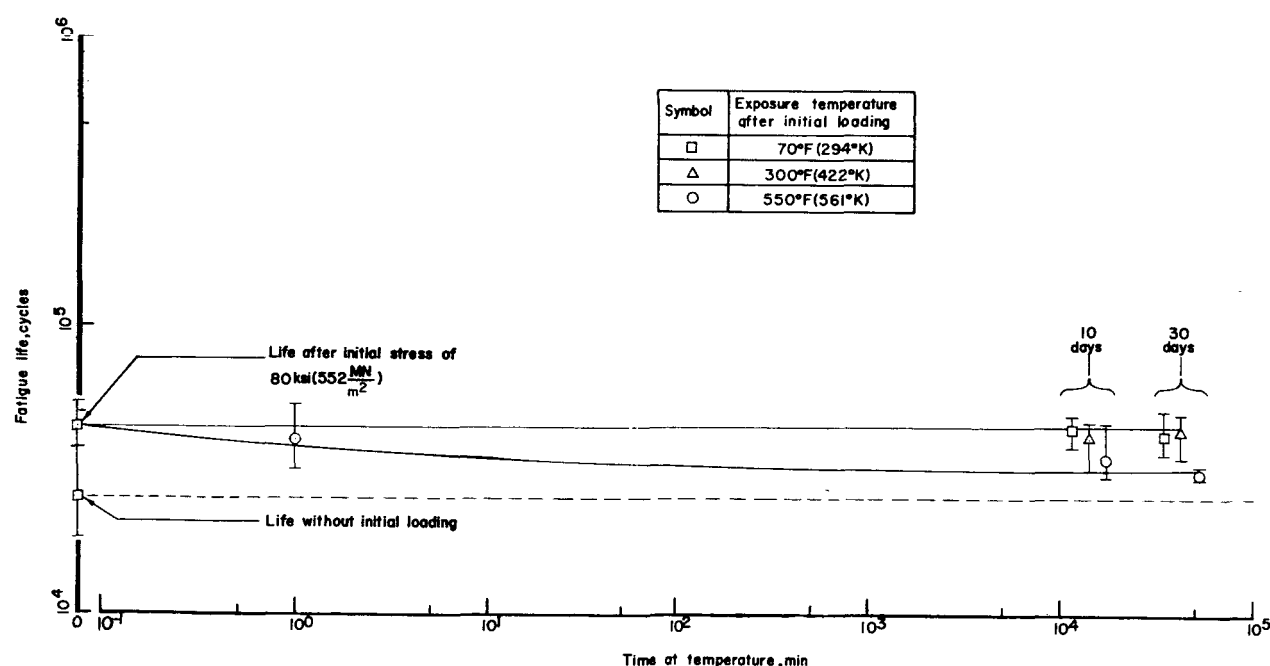


Figure 7.- The effect of exposure to elevated temperature on the room-temperature fatigue life of notched ($K_t = 4$) specimens of duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet loaded at 80 ksi (552 MN/m²). Cyclic stress range: 0 to 50 ksi (0 to 345 MN/m²).

and 300° F (294° and 422° K) had practically no effect on fatigue life. For exposure at 550° F (561° K), a small decrease in fatigue life was observed. In this case, the decrease in fatigue life did not occur as rapidly as it had for the specimens conditioned at 100 ksi (690 MN/m²). As will be discussed in the next section, the calculated residual stress resulting from loading at 80 ksi (552 MN/m²) was considerably lower than that resulting from loading at 100 ksi (690 MN/m²). Thus, a smaller reduction in residual stress could be expected from specimens loaded at 80 ksi (552 MN/m²) when they were heated. Again, the fatigue lives did not reduce to the reference level. In an attempt to

explain the reduction in fatigue life after exposure of initially loaded specimens to elevated temperature, photomicrographs ($\times 800$) were taken from samples of the notch-root material with and without exposure. The material for the exposed sample was from a specimen that had been loaded at 100 ksi (690 MN/m^2) and exposed 30 days at 550° F (561° K). The other sample was from as-received material. No difference between the photomicrographs was observed.

Calculations of Residual Stress

Calculations of the residual stresses at the notch root due to initial loading were made to substantiate the viewpoint presented previously. The calculations were made by means of the method developed by Crews (ref. 10). In general, the procedure consists of determining the cyclic stress-strain curve and calculating stresses from it. For the present tests, the stress-strain curve was determined through one sequence of tensile loading, unloading, and reloading in compression and is presented as figure 8. To

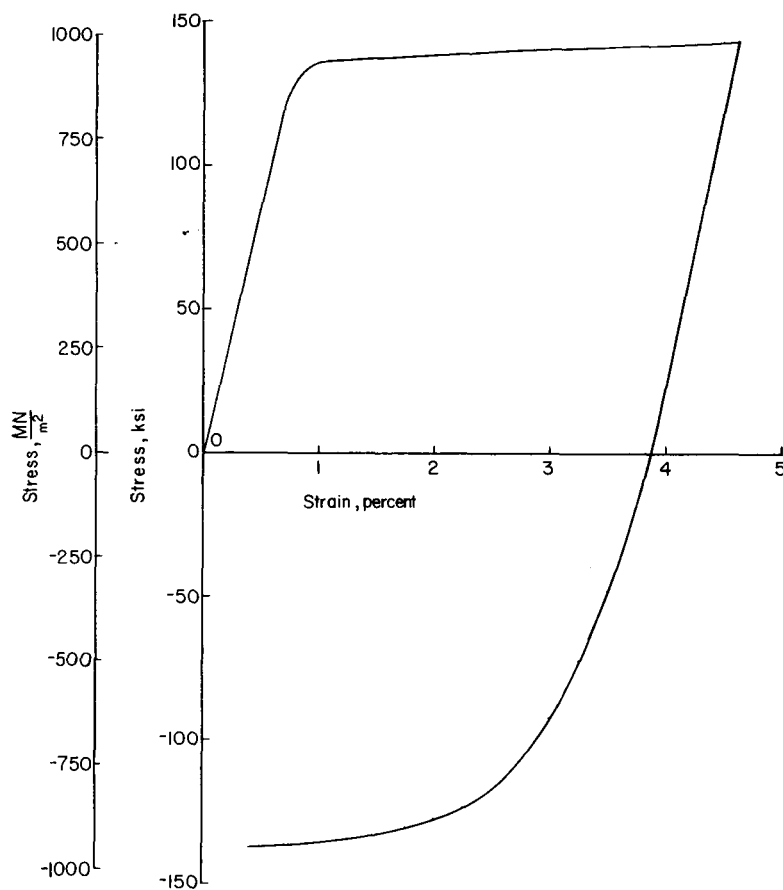


Figure 8.- Stress-strain curve for duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet for tensile loading, unloading, and reloading in compression.

facilitate application of Crews' approach, the following assumptions were made: (1) The virgin compressive stress-strain curve was identical to the virgin tensile stress-strain curve, (2) unloading portions of stress-strain curves were identical whether initial loading was tensile or compressive, and (3) the curvatures of unloading portions of stress-strain curves were identical regardless of the strain level achieved during the loading of the specimen. The calculated maximum and residual local stresses due to initial loading are presented in table V(a) and figure 9. As indicated by the figure, local residual

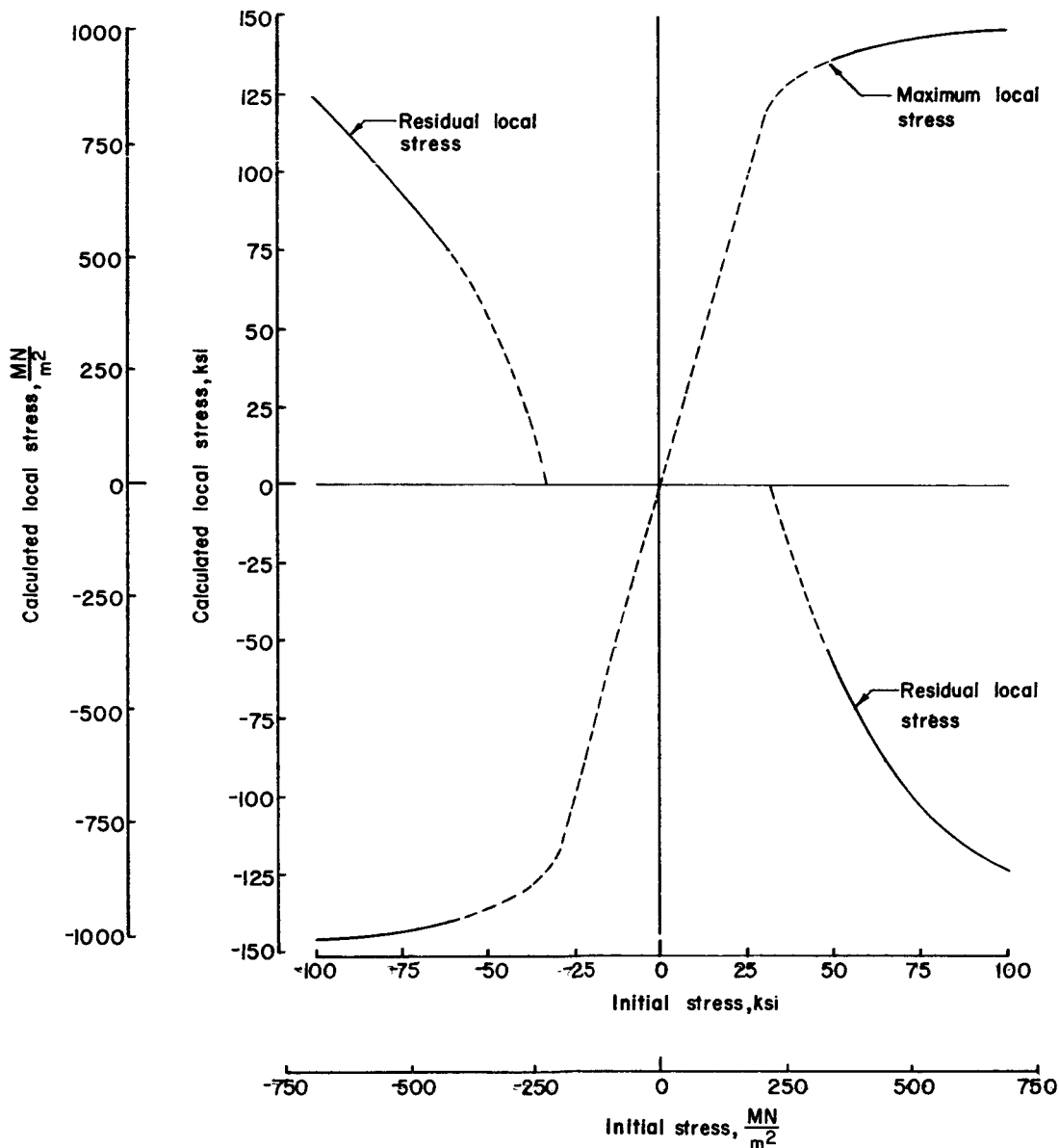


Figure 9.- Calculated local stresses resulting from a single application of initial load to notched ($K_T = 4$) specimens of duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet.

stresses were present only if the maximum local stress exceeded yield, and the residual stresses were opposite in sign to the applied loading. High maximum local stresses produced disproportionately large residual stresses upon unloading.

To determine the local stresses occurring during the first cycle of the fatigue test, the change in local stress due to application of the fatigue loading was added algebraically to the residual stress already present due to the initial loading. The local stresses thus determined are presented in table V(b) and in figure 10. For initial tensile loading, the curve labeled "Minimum local stress" in figure 10 is the same as the curve labeled

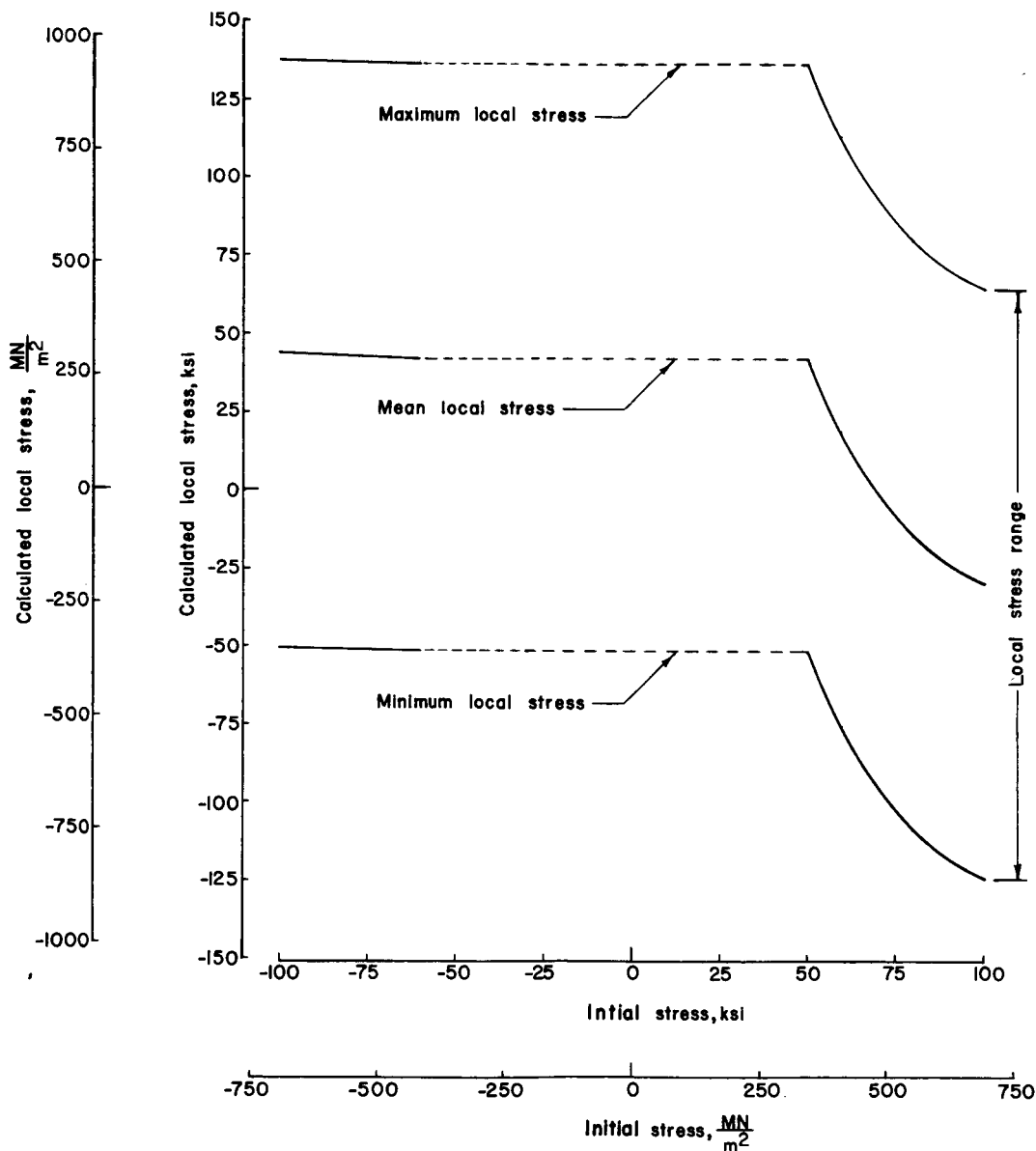


Figure 10.- Calculated local stresses during the first cycle of fatigue loading at 0 to 50 ksi (0 to 345 MN/m^2) after an initial tensile load. Calculations are for notched ($K_T = 4$) specimens of duplex-annealed Ti-8Al-1Mo-1V titanium-alloy sheet.

"Residual local stress" in figure 9. Superposition of the calculated stress range due to the fatigue loading results in the curve labeled "Maximum local stress" in figure 10. The curve labeled "Mean local stress" is simply the arithmetic average of the other two curves. As seen in figure 10, initial tensile stresses greater than the maximum fatigue stress $[50 \text{ ksi } (345 \text{ MN/m}^2)]$ caused the local stresses to become increasingly negative as the magnitude of the initial stress increased.

Calculations yield the same local stresses for the first cycle of the fatigue test for specimens not loaded initially and for those loaded at 50 ksi (345 MN/m²) because 50 ksi was the maximum stress in the fatigue test. For initial compressive loading, addition of the fatigue loading to the local tensile residual stress (fig. 9) caused yielding in tension. As a result of the tensile yielding, the local-stress range during fatigue was approximately the same as that for specimens which were not loaded initially.

Thus, the calculations support the observed effects of initial loading on fatigue life presented in the previous sections of this paper and provide an explanation for the fatigue behavior presented in figure 5.

CONCLUSIONS

An investigation was conducted to study the effects of initial high loads and of exposure to moderately elevated temperatures on the room-temperature fatigue life of Ti-8Al-1Mo-1V titanium-alloy sheet. The results, which are based on tests of notched specimens having stress-concentration factors of 4 support the following conclusions:

1. A large initial tensile load increased the fatigue life appreciably, whereas a large initial compressive load decreased the fatigue life somewhat.

2. Exposures up to 30 days at 300° and 550° F (422° and 561° K) reduced the fatigue life after a high initial tensile load. The reduction was most pronounced at the higher temperature for the highest initial load. Most of the reduction occurred after only a short exposure in the case of the highest initial load. Exposure at 70° F (294° K) had no effect on fatigue life.

3. The fatigue life of specimens subjected to an initial high tensile load did not reduce to the reference level of fatigue life after exposure at 300° or 550° F (422° or 561° K).

4. Calculations showed that an initial high tensile load induced local compressive residual stresses which increased the fatigue life. An initial high compressive load induced local tensile residual stresses which decreased the fatigue life.

Langley Research Center,

National Aeronautics and Space Administration,

Langley Station, Hampton, Va., February 15, 1967,

126-14-03-06-23.

APPENDIX A

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

The International System of Units (SI) was adopted by the Eleventh General Conference on Weights and Measures, Paris, October 1960, in Resolution No. 12 (ref. 7). Conversion factors for the units used herein are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI Unit (**)
Length	in.	0.0254	meter (m)
Temperature . . .	°F	$\frac{5}{9} (F + 459.67)$	degrees Kelvin (°K)
Force	lbf	4.448	newton (N)
Stress	ksi = $\frac{1000 \text{ lbf}}{\text{in}^2}$	6.895×10^6	newtons/meter ² (N/m ²)

*Multiply value given in U.S. Customary Units by conversion factor to obtain equivalent value in SI Units or apply formula.

**Prefixes to indicate multiples of units are as follows:

Prefix	Abbreviation	Value
milli	m	10^{-3}
kilo	k	10^3
mega	M	10^6
giga	G	10^9

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**TABLE I.- TENSILE PROPERTIES AND CHEMICAL COMPOSITION OF
 DUPLEX-ANNEALED Ti-8Al-1Mo-1V TITANIUM-ALLOY SHEET
 0.050 INCH (1.27 mm) THICK**

(a) Tensile properties (tabulations are averages of 16 tests)

Sheet	Ultimate tensile strength		Tensile yield strength at 0.2-percent offset		Elongation in 2 inches (51 mm), percent	Young's modulus	
	ksi	MN/m ²	ksi	MN/m ²		ksi	GN/m ²
29	144.9	999	132.1	911	13.0	16.7×10^3	115
30	150.4	1037	136.9	944	12.5	17.2	119
34	151.0	1041	136.9	944	12.7	16.9	116
35	149.1	1028	135.3	933	12.3	16.6	114

(b) Chemical composition supplied by manufacturer

Constituent	C	Fe	N	Al	V	Mo	H	Ti
Percentage by weight . . .	0.026	0.11	0.011	7.9	1.0	1.1	0.003 to 0.006	Balance

TABLE II.- FATIGUE LIVES OF NOTCHED ($K_T = 4$) SPECIMENS OF
 DUPLEX-ANNEALED Ti-8Al-1Mo-1V TITANIUM-ALLOY SHEET
 0.050 INCH (1.27 mm) THICK AFTER INITIAL LOADING
 [Cyclic stress range: 0 to 50 ksi (0 to 345 MN/m²)]

Initial stress		Specimen	Fatigue life, cycles	
ksi	MN/m ²		Individual	Geometric mean
None	None	TC30A81	18 390	25 300
		TC34A63	20 730	
		TC30A74	21 710	
		TC30A80	24 320	
		TC34A16	24 860	
		TC34A97	29 480	
		TC30A79	34 430	
		TC30A38	39 000	
60	414	TC30A42	20 290	28 280
		TC30A24	26 360	
		TC30A1	28 660	
		TC30A37	34 020	
		TC30A49	35 500	
-60	-414	TC30A46	22 680	24 080
		TC30A20	24 240	
		TC30A94	24 290	
		TC30A54	24 320	
		TC30A88	24 650	
80	552	TC30A29	37 250	44 590
		TC30A45	38 250	
		TC30A30	47 280	
		TC30A19	48 390	
		TC30A64	54 090	
100	690	TC30A47	96 650	144 800
		TC30A96	118 440	
		TC30A13	150 940	
		TC30A87	152 050	
		TC35A59	157 020	
		TC30A39	166 650	
		TC30A22	193 880	
		TC30A48	* $>10^6$	
		TC30A8	* $>10^6$	
-100	-690	TC30A70	14 860	16 250
		TC30A83	15 700	
		TC30A23	15 910	
		TC30A17	16 520	
		TC30A71	18 500	

*Not included in calculation of geometric mean fatigue life.

**TABLE III.- FATIGUE LIVES OF NOTCHED ($K_T = 4$) SPECIMENS OF
 DUPLEX-ANNEALED Ti-8Al-1Mo-1V TITANIUM-ALLOY SHEET
 0.050 INCH (1.27 mm) THICK AFTER INITIAL LOADING AT
 100 ksi (690 MN/m²) AND EXPOSURE TO 70^o, 300^o,
 AND 550^o F (294^o, 422^o, AND 561^o K)
 [Cyclic stress range: 0 to 50 ksi (0 to 345 MN/m²)]**

Exposure conditions			Specimen	Fatigue life, cycles	
Temperature		Duration, min		Individual	Geometric mean
°F	°K				
70	294	14 400 (10 days)	TC34A64 TC34A23 TC34A88 TC34A51 TC34A50	119 000 123 000 169 250 *>10 ⁶ *>10 ⁶	135 300
		43 200 (30 days)	TC35A11 TC34A84 TC34A91 TC34A90 TC34A11	127 000 185 000 420 540 *>10 ⁶ *>10 ⁶	214 560
300	422	0.33 (20 sec)	TC37A71 TC37A75 TC37A58 TC37A38 TC37A27	51 270 61 930 63 630 88 790 341 130	90 600
		60	TC35A33 TC35A30 TC35A31 TC35A80 TC35A62	58 870 73 710 76 040 90 070 103 730	79 020
		14 400 (10 days)	TC34A12 TC34A46 TC34A45 TC34A56 TC34A47	73 130 83 500 102 260 105 580 125 760	96 340
		43 200 (30 days)	TC34A80 TC34A17 TC34A95 TC34A72 TC34A10	61 360 72 770 75 300 79 020 117 350	79 220

*Not included in calculation of geometric mean fatigue life.

TABLE III.- FATIGUE LIVES OF NOTCHED ($K_T = 4$) SPECIMENS OF
 DUPLEX-ANNEALED Ti-8Al-1Mo-1V TITANIUM-ALLOY SHEET
 0.050 INCH (1.27 mm) THICK AFTER INITIAL LOADING AT
 100 ksi (690 MN/m²) AND EXPOSURE TO 70°, 300°,
 AND 550° F (294°, 422°, AND 561° K) - Concluded

Exposure conditions		Specimen	Fatigue life, cycles		
Temperature			Individual	Geometric mean	
°F	°K				
550	561	0.33 (20 sec)	TC29A7 TC29A17 TC29A66 TC29A4 TC29A80	28 130 54 570 59 410 64 110 85 670	54 950
		1	TC35A83 TC35A93 TC35A75 TC35A94 TC35A7	58 410 66 160 66 840 67 480 74 990	66 570
		60	TC35A41 TC35A48 TC35A49 TC35A16 TC35A66	52 070 54 330 61 460 62 580 62 680	58 450
		360 (6 hours)	TC35A2 TC35A42 TC35A47 TC35A32 TC35A36 TC35A68	38 360 51 450 57 220 65 890 79 540 79 960	60 140
		1200 (20 hours)	TC34A70 TC34A31 TC35A26 TC34A96 TC34A62 TC34A13	56 550 56 610 60 680 64 770 68 730 88 430	65 150
		7200 (5 days)	TC34A2 TC34A75 TC34A3 TC34A99 TC34A5	23 350 49 380 50 890 55 430 58 910	45 340
		14 400 (10 days)	TC30A32 TC30A41 TC30A51 TC30A92 TC34A61	37 410 44 850 45 390 48 760 50 550	45 150
		43 200 (30 days)	TC30A33 TC30A43 TC30A55 TC30A14 TC30A72	39 330 40 610 41 200 43 290 45 820	41 990
			TC34A4 TC34A18 TC34A41 TC34A20 TC34A6	16 640 17 380 18 580 20 980 22 420	*19 000

*The specimens in this group were subjected to 30 days of exposure at 550° F (561° K) without having been loaded initially.

TABLE IV.- FATIGUE LIVES OF NOTCHED ($K_T = 4$) SPECIMENS OF
 DUPLEX-ANNEALED Ti-8Al-1Mo-1V TITANIUM-ALLOY SHEET
 0.050 INCH (1.27 mm) THICK AFTER INITIAL LOADING AT
 80 ksi (552 MN/m²) AND EXPOSURE TO 70°, 300°,
 AND 550° F (294°, 422°, AND 561° K)
 [Cyclic stress range: 0 to 50 ksi (0 to 345 MN/m²)]

Exposure conditions			Specimen	Fatigue life, cycles	
Temperature		Duration, min		Individual	Geometric mean
°F	°K				
70	294	14 400 (10 days)	TC30A28	37 730	43 800
			TC30A89	41 860	
			TC30A56	43 340	
			TC35A19	48 060	
			TC30A11	48 730	
		43 200 (30 days)	TC30A35	35 920	41 300
TC30A36	37 130				
TC30A93	39 060				
TC30A16	42 350				
TC30A12	50 810				
300	422	14 400 (10 days)	TC34A37	31 520	40 500
			TC34A7	40 850	
			TC34A93	41 440	
			TC34A76	43 250	
			TC34A86	46 300	
		43 200 (30 days)	TC34A87	35 330	43 000
TC34A43	41 740				
TC34A58	43 640				
TC34A81	47 030				
TC34A40	49 880				
550	561	1	TC37A67	31 990	40 000
			TC35A64	37 320	
			TC37A44	37 890	
			TC35A44	38 450	
			TC35A8	38 560	
			TC37A97	38 720	
			TC37A56	41 620	
			TC35A34	42 020	
			TC35A5	42 090	
			TC37A72	53 290	
		14 400 (10 days)	TC34A39	30 080	35 000
			TC30A76	30 960	
			TC34A48	34 730	
			TC34A49	35 450	
			TC34A68	46 830	
43 200 (30 days)	TC34A53	29 540	30 700		
	TC34A52	30 170			
	TC34A44	30 510			
	TC34A24	30 890			
	TC34A89	32 890			

TABLE V.- CALCULATED LOCAL STRESSES FOR NOTCHED
($K_T = 4$) SPECIMENS OF DUPLEX-ANNEALED
Ti-8Al-1Mo-1V TITANIUM-ALLOY SHEET
0.050 INCH (1.27 mm) THICK

(a) Stresses associated with initial load

Initial stress		Local stresses associated with initial load (*)			
		Maximum		Residual	
ksi	MN/m ²	ksi	MN/m ²	ksi	MN/m ²
50	345	137	944	-52	-359
60	414	139	958	-75	-517
80	552	141	972	-109	-751
100	690	146	1007	-124	-855
-60	-414	-139	-958	75	517
-100	-690	-146	-1007	124	855

(b) Stresses occurring during first cycle

Initial stress		First-cycle local stresses associated with the fatigue-stress cycle (*)			
		Maximum		Minimum	
ksi	MN/m ²	ksi	MN/m ²	ksi	MN/m ²
50	345	137	944	-52	-359
60	414	114	786	-75	-517
80	552	80	552	-109	-751
100	690	65	448	-124	-855
-60	-414	136	938	-52	-359
-100	-690	138	951	-51	-352

*Calculated using the method developed by Crews (ref. 10).